CONTENTS

PAGE

Action of Magnets on Light 3
  Object 4
  Definition of Terms 4
  Discovery of Rotation by Glass 5
  Description of Phenomena 6
  Laws of Rotation 7
  Substances Producing Rotation 10
  Rotation in Crystalline Substances 11
  Rotation in Gases 12
Action of Electric Currents 12
  Repetition of Experiments with. (*Omitted.*)
General Considerations 12
  Action through Matter 14
  Nature of Action 15
  Relation between Natural and Magnetic Rotation 16

CONTENTS

PAGE

Increased Rotation by Multiple Reflection 23
Rotation in Air 25
Rotation in Crystals 25

ON THE MAGNETIZATION OF LIGHT AND THE ILLUMINATION OF MAGNETIC LINES OF FORCE*

BY

MICHAEL FARADAY, F. R. S.

I. ACTION OF MAGNETS ON LIGHT

2146.† I HAVE long held an opinion, almost amounting to conviction, in common, I believe, with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin; or, in other words, are so directly related and mutually dependent that they are convertible, as it were, one into another, and possess equivalents of power in their action.* In modern times the proofs of their convertibility have been accumulated to a very considerable extent, and a commencement made of the determination of their equivalent forces.

---

* The title of this paper has, I understand, led many to a misapprehension of its contents, and I therefore take the liberty of appending this explanatory note. Neither accepting nor rejecting the hypothesis of an ether, or the corpuscular or any other view that may be entertained of the nature of light; and, as far as I can see, nothing being really known of a ray of light more than of a line of magnetic or electric force, or even of a line of gravitating force, except as it and they are manifest in and by substances; I believe that, in the experiments I describe in the paper, light has been magnetically affected, *i. e.*, that that which is magnetic in the forces of matter has been affected, and in turn has affected that which is truly magnetic in the force of light. By the term magnetic I include here either of the peculiar exertions of the power of a magnet, whether it be that which is manifest in the magnetic or the diamagnetic class of bodies. The phrase "illumination of the lines of magnetic force" has been understood to imply that I had rendered them luminous. This was not within my thought. I intended to express that the line of magnetic force was illuminated as the earth is illuminated by the sun, or the spider's web illuminated by the astronomer's lamp. Employing a ray of light, we can tell, *by the eye*, the direction of the magnetic lines through a body; and by the alteration of the ray and its optical effect on the eye can see the course of the lines just as we can see the course of a thread of glass, or any other transparent substance, rendered visible by the light; and this was what I meant by *illumination*, as the paper fully explains.—December 15, 1845. M. F.

† [*The numbers at the beginning of the paragraphs refer to those in the Experimental Researches.*]

2147. This strong persuasion extended to the powers of light, and led, on a former occasion, to many exertions having for their object the discovery of the direct relation of light and electricity and their mutual action in bodies subject jointly to their power,† but the results were negative, and were afterwards confirmed, in that respect, by Wartmann.‡

2148. These ineffectual exertions, and many others which were never published, could not remove my strong persuasion derived from philosophical considerations; and, therefore, I recently resumed the inquiry by experiment in a most strict and searching manner, and have at last succeeded in *magnetizing and electrifying a ray of light and in illuminating a magnetic line of force.* These results, without entering into the detail of many unproductive experiments, I will describe as briefly and clearly as I can.

2149. But before I proceed to them I will define the meaning I connect with certain terms which I shall have occasion to use:—thus, by *line of magnetic force*, or *magnetic line of force*, or *magnetic curve,* I mean that exercise of magnetic force which is exerted in the lines usually called magnetic curves, and which equally exist as passing from or to magnetic poles, or forming concentric circles round an electric current. By *line of electric force,* I mean the force exerted in the lines joining two bodies acting on each other according to the principles of static electric induction (1161, etc.), which may also be either in curved or straight lines. By a *diamagnetic,* I mean a body through which lines of magnetic force are passing, and which does not by their action assume the usual magnetic state of iron or loadstone.

---

* *Exp. Res.*, 57, 366, 376, 877, 961, 2071.

† *Phil. Trans.*, 1834. *Exp. Res.*, 951-955. [*Efforts to discover effects of electricity on polarized light.*]

‡ *Archives de l'Électricité*, ii., pp. 596–600.

2150. A ray of light issuing from an Argand lamp was polarized in a horizontal plane by reflection from a surface of glass, and the polarized ray passed through a Nicol's eye-piece revolving on a horizontal axis, so as to be easily examined by the latter. Between the polarizing mirror and the eye-piece two powerful electromagnetic poles were arranged, being either the poles of a horse-shoe magnet or the contrary poles of two cylinder magnets; they were separated from each other about two inches in the direction of the line of the ray, and so placed that, if on the same side of the polarized ray, it might pass near them; or, if on contrary sides, it might go between them, its direction being always parallel, or nearly so, to the magnetic lines of force (2149). After that, any transparent substance placed between the two poles would have passing through it both the polarized ray and the magnetic lines of force at the same time and in the same direction.

2151. Sixteen years ago I published certain experiments made upon optical glass * and described the formation and general characters of one variety of heavy glass, which, from its materials, was called silicated borate of lead. It was this glass which first gave me the discovery of the relation between light and magnetism, and it has power to illustrate it in a degree beyond that of any other body. For the sake of perspicuity I will first describe the phenomena as presented by this substance.

2152. A piece of this glass; about two inches square and 0.5 of an inch thick, having flat and polished edges, was placed in a *diamagnetic* (2149) between the poles (not as yet magnetized by the electric current), so that the polarized ray should pass through its length; the glass acted as air, water, or any other indifferent substance would do; and if the eye-piece were previously turned into such a position that the polarized ray was extinguished, or rather the image produced by it rendered invisible, then the introduction of this glass made no alteration in that respect. In this state of circumstances the force of the electromagnet was developed by sending an electric current through its coils, and immediately the image of the lamp flame became visible, and continued so as long as the arrangement continued magnetic. On stopping the electric current, and so causing the magnetic force to cease, the light instantly disappeared. These phenomena could be renewed at pleasure, at any instant of time, and upon any occasion, showing a perfect dependence of cause and effect.

---

* *Phil. Trans.*, 1830, p. 1.

2153. The voltaic current which I used upon this occasion was that of five pair of Grove's construction, and the electro-magnets were of such power that the poles would singly sustain a weight of from twenty-eight to fifty-six, or more, pounds. A person looking for the phenomenon for the first time would not be able to see it with a weak magnet.

2154. The character of the force thus impressed upon the diamagnetic is that of *rotation;* for when the image of the lamp flame has thus been rendered visible, revolution of the eye-piece to the right or left, more or less, will cause its extinction; and the further motion of the eye-piece to the one side or other of this position will produce the reappearance of the light, and that with complementary tints, according as this further motion is to the right or left hand.

2155. When the pole nearest to the observer was a marked pole, *i. e.*, the same as the north end of a magnetic needle, and the further pole was unmarked, the rotation of the ray was right-handed; for the eye-piece had to be turned to the right hand, or clock fashion, to overtake the ray and restore the image to its first condition. When the poles were reversed, which was instantly done by changing the direction of the electric current, the rotation was changed also and became left-handed, the alteration being to an equal degree in extent as before. The direction was always the same for the same *line of magnetic force.*

2156. When the diamagnetic was placed in the numerous other positions which can easily be conceived about the magnetic poles, results were obtained more or less marked in extent and very definite in character, but of which the phenomena just described may be considered as the chief example; they will be referred to, as far as is necessary, hereafter.

2157. The same phenomena were produced in the silicated borate of lead by the action of a good ordinary steel horse-shoe magnet, no electric current being now used. The results were feeble, but still sufficient to show the perfect identity of action between electromagnets and common magnets in this their power over light.

2158. Two magnetic poles were employed end-ways, *i. e.*, the cores of the electromagnets were hollow iron cylinders, and the ray of polarized light passed along their axes and through the diamagnetic placed between them: the effect was the same.

2159. One magnetic pole only was used, that being one end of a powerful cylinder electromagnet. When the heavy glass was beyond the magnet, being close to it, but between the magnet and the polarizing reflector, the rotation was in one direction, dependent on the nature of the pole; when the diamagnetic was on the near side, being close to it but between it and the eye, the rotation for the same pole was in the contrary direction to what it was before; and when the magnetic pole was changed both these directions were changed with it. When the heavy glass was placed in a corresponding position to the pole, but above or below it, so that the *magnetic curves* were no longer passing through the glass parallel to the ray of polarized light, but rather perpendicular to it, then no effect was produced. These particularities may be understood by reference to Fig. 1, where *a* and *b* represent the first positions of the diamagnetic, and *c* and *d* the latter positions, the course of the ray being marked by the dotted line. If, also, the glass were placed directly at the end of the magnet, then no effect was produced on a ray passing in the direction here described, though it is evident, from what has been already said (2155), that a ray passing *parallel* to the magnetic lines through the glass so placed would have been affected by it.

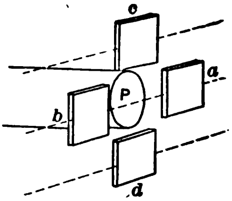

Fig. 1

2160. Magnetic lines, then, in passing through silicated borate of lead, and a great number of other substances (2173), cause these bodies to act upon a polarized ray of light when the lines are parallel to the ray, or in proportion as they are parallel to it. If they are perpendicular to the ray, they have no action upon it. They give the diamagnetic the power of rotating the ray; and the *law* of this action on light is, that if a magnetic line of force be *going from* a north pole or *coming* from a south pole, along the path of a polarized ray coming to the observer, it will rotate that ray to the right hand; or, that if such a line of force be coming from a north pole or going from a south pole, it will rotate such a ray to the left hand.

2161. If a cork or a cylinder of glass, representing the diamagnetic, be marked at its ends with the letters N and S, to represent the poles of a magnet, the line joining these letters may be considered as a magnetic line of force; and, further, if a line be traced round the cylinder with arrow heads on it to represent direction, as in the figure [2], such a simple model, held up before the eye, will express the whole of the law, and give every position and consequence of direction resulting from it. If a watch be considered as the diamagnetic, the north pole of a magnet being imagined against the face, and a south pole against the back, then the motion of the hands will indicate the direction of rotation which a ray of light undergoes by magnetization.

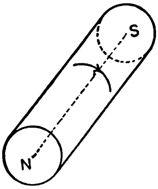

Fig. 2

2162. I will now proceed to the different circumstances which affect, limit, and define the extent and nature of this new power of action on light.

2163. In the first place, the rotation appears to be in proportion to the extent of the diamagnetic through which the ray and the magnetic lines pass. I preserved the strength of the magnet and the interval between its poles constant, and then interposed different pieces of the same heavy glass (2151) between the poles. The greater the extent of the diamagnetic in the line of the ray, whether in one, two, or three pieces, the greater was the rotation of the ray; and, as far as I could judge by these first experiments, the amount of rotation was exactly proportionate to the extent of diamagnetic through which the ray passed. No addition or diminution of the heavy glass on the *side* of the course of the ray made any difference in the effect of that part through which the ray passed.

2164. The power of rotating the ray of light *increased* with the intensity of the magnetic lines of force. This general effect is very easily ascertained by the use of electromagnets; and, within such range of power as I have employed, it appears to be directly proportionate to the intensity of the magnetic force.

2165. Other bodies, besides the heavy glass, possess the same power of becoming, under the influence of magnetic force, active on light (2173). When these bodies possess a rotative power of their own, as is the case with oil of turpentine, sugar, tartaric acid, tartrates, etc., the effect of the magnetic force is to add to or subtract from their specific force, according as the natural rotation and that induced by the magnetism is right or left handed (2231).

2166. I could not perceive that this power was affected by any degree of motion which I was able to communicate to the diamagnetic whilst jointly subject to the action of the magnetism and the light.

2167. The interposition of copper, lead, tin, silver, and other ordinary non-magnetic bodies in the course of the magnetic curves, either between the pole and the diamagnetic, or in other positions, produced no effect either in kind or degree upon the phenomena.

2168. Iron frequently affected the results in a very considerable degree; but it always appeared to be either by altering the direction of the magnetic lines or disposing within itself of their force. Thus, when the two contrary poles were on one side of the polarized ray (2150), and the heavy glass in its best position between them and in the ray (2152), the bringing of a large piece of iron near to the glass on the other side of the ray caused the power of the diamagnetic to fall. This was because certain lines of magnetic force, which at first passed through the glass parallel to the ray, now crossed the glass and the ray; the iron giving two contrary poles opposite the poles of the magnet, and thus determining a new course for a certain portion of the magnetic power, and that across the polarized ray.

2169. Or, if the iron, instead of being applied on the opposite side of the glass, were applied on the same side with the magnet, either near it or in contact with it, then, again, the power of the diamagnetic fell, simply because the power of the magnet was diverted from it into a new direction. These effects depend much, of course, on the intensity and power of the magnet, and on the size and softness of the iron.

2170. The electro-helices (2190) without the iron cores were very feeble in power, and, indeed, hardly sensible in their effect. With the iron cores they were powerful, though no more electricity was then passing through the coils than before (1071). This shows, in a very simple manner, that the phenomena exhibited by light under these circumstances is directly connected with the magnetic form of force supplied by the arrangement. Another effect which occurred illustrated the same point. When the contact at the voltaic battery is made, and the current sent round the electromagnet, the image produced by the rotation of the polarized ray does not rise up to its full lustre immediately, but increases for a couple of seconds, gradually acquiring its greatest intensity; on breaking the contact, it sinks instantly and disappears apparently at once. The gradual rise in brightness is due to the *time* which the iron core of the magnet requires to evolve all that magnetic power which the electric current can develop in it; and as the magnetism rises in intensity, so does its effect on the light increase in power; hence the progressive condition of the rotation.

2171. I cannot as yet find that the heavy glass (2151), when in this state, *i. e.*, with magnetic lines of force passing through it, exhibits any increased degree or has any specific magneto-inductive action of the recognized kind. I have placed it in large quantities, and in different positions, between magnets and magnetic needles, having at the time very delicate means of appreciating any difference between it and air, but could find none.*

2172. Using water, alcohol, mercury, and other fluids contained in very large delicate thermometer-shaped vessels, I could not discover that any difference in volume occurred when the magnetic curves passed through them.

2173. It is time that I should pass to a consideration of this power of magnetism over light as exercised, not only in the silicated borate of lead (2151), but in many other substances; and here we perceive, in the first place, that if all transparent bodies possess the power of exhibiting the action, they have it in very different degrees, and that up to this time there are some that have not shown it at all.

2174. Next, we may observe that bodies that are exceedingly different to each other in chemical, physical, and mechanical properties develop this effect; for solids and liquids, acids, alkalies, oils, water, alcohol, ether, all possess the power.

---

* [*In a later series of experiments Faraday discovered that practically all bodies have paramagnetic or diamagnetic properties.*]

2175. And, lastly, we may observe that in all of them, though the degree of action may differ, still it is always the same in kind, being a rotative power over the ray of light; and, further, the direction of the rotation is, in every case, independent of the nature or state of the substance, and dependent upon the direction of the magnetic line of force, according to the law before laid down (2160).

[2176 *omitted.*]

2177. Whilst employing crystalline bodies as diamagnetics, I generally gave them that position in which they did not affect the polarized ray, and then induced the magnetic curves through them. As a class, they seemed to resist the assumption of the rotating state. *Rock-salt* and *fluorspar* gave evidence of the power in a slight degree; and I think that a crystal of alum did the same, but its ray length in the transparent part was so small that I could not ascertain the fact decisively. Two specimens of transparent fluor, lent me by Mr. Tennant, gave the effect.

2178. Rock crystal, four inches across, gave no indications of action on the ray, neither did smaller crystals, nor cubes about three-fourths of an inch in the side, which were so cut as to have two of their faces perpendicular to the axis of the crystal, though they were examined in every direction.

2179. *Iceland spar* exhibited no signs of effect, either in the form of rhomboids or of cubes like those just described.

2180. *Sulphate of baryta, sulphate of lime,* and *carbonate of soda* were also without action on the light.

2181. A piece of fine clear *ice* gave me no effect. I cannot, however, say there is none, for the effect of water in the same mass would be very small, and the irregularity of the flattened surface from the fusion of the ice and flow of water made the observation very difficult.

2182. With some degree of curiosity and hope, I put gold-leaf into the magnetic lines, but could perceive no effect. Considering the extremely small dimensions of the length of the path of the polarized ray in it, any positive result was hardly to be expected.

[*Par.* 2183–2185, *describing experiments on many fixed and essential oils and aqueous solutions, are omitted.*]

2186. Proceeding from liquids to air and gaseous bodies, I have here to state that, as yet, I have not been able to detect the exercise of this power in any one of the substances in this class. I have tried the experiment with bottles four inches in diameter and the following gases: oxygen, nitrogen, hydrogen, nitrous oxide, olefiant gas, sulphurous acid, muriatic acid, carbonic acid, carbonic oxide, ammonia, sulphuretted hydrogen, and bromine vapor, at ordinary temperatures; but they all gave negative results. With air the trial has been carried, by another form of apparatus,* to a much higher degree, but still ineffectually.

[2187, 2188 *omitted.*]

II. ACTION OF ELECTRIC CURRENTS ON LIGHT.

2189. From a consideration of the nature and position of the lines of magnetic and electric force, and the relation of a magnet to a current of electricity, it appeared almost certain that an electric current would give the same result of action on light as a magnet; and, in the helix, would supply a form of apparatus in which great lengths of diamagnetics, and especially of such bodies as appeared to be but little affected between the poles of the magnet, might be submitted to examination and their effect exalted. This expectation was, by experiment, realized.

[2190–2220 *omitted.*]

III. GENERAL CONSIDERATIONS.

2221. Thus is established, I think for the first time,† a true, direct relation and dependence between light and the magnetic and electric forces; and thus a great addition made to the facts and considerations which tend to prove that all natural forces are tied together, and have one common origin (2146). It is, no doubt, difficult in the present state of our knowledge to express our expectation in exact terms; and, though I have said that another of the powers of nature is, in these experiments, directly related to the rest, I ought, perhaps, rather to say that another form of the great power is distinctly and directly related to the other forms, or that the great power manifested by particular phenomena in particular forms is here further identified and recognized, by the direct relation of its form of light to its forms of electricity and magnetism.

---

* [*See pp.* 24, 25.]

† I say for the first time, because I do not think that the experiments of Morichini on the production of magnetism by the rays at the violet end of the spectrum prove any such relation. When in Rome with Sir H. Davy in the month of May, 1814, I spent several hours at the house of Morichini, working with his apparatus and under his directions, but could not succeed in magnetizing a needle. I have no confidence in the effect as a *direct* result of the action of the sun's rays; but think that when it has occurred it has been secondary, incidental, and perhaps even accidental; a result that might well happen with a needle that was preserved during the whole experiment in a north and south position.

2222. The relation existing between *polarized* light and magnetism and electricity is even more interesting than if it had been shown to exist with common light only. It cannot but extend to common light, and as it belongs to light made, in a certain respect, more precise in its character and properties by polarization, it collates and connects it with these powers in that duality of character which they possess, and yields an opening, which before was wanting to us, for the appliance of these powers to the investigation of the nature of this and other radiant agencies.

2223. Referring to the conventional distinction before made (2149), it may be again stated that it is the magnetic lines of force *only* which are effectual on the rays of light, and they *only* (in appearance) when parallel to the ray of light, or as they tend to parallelism with it. As, in reference to matter not magnetic after the manner of iron, the phenomena of electric induction and electrolyzation show a vast superiority in the energy with which electric forces can act as compared with magnetic forces, so here, in another direction and in the peculiar and correspondent effects which belong to magnetic forces, they are shown, in turn, to possess great superiority, and to have their full equivalent of action on the same kind of matter.

2224. The magnetic forces do not act on the ray of light di-

January 2, 1846.—I should not have written "for the first time," as above, if I had remembered Mr. Christie's experiments and papers "On the Influence of the Solar Rays on Magnets," communicated in the *Philosophical Transactions* for 1826, p. 219, and 1828, p. 379.—M. F rectly and without the intervention of matter, but through the mediation of the substance in which they and the ray have a simultaneous existence, the substances and the forces giving to and receiving from each other the power of acting on the light. This is shown by the non-action of a vacuum, of air or gases; and it is also further shown by the special degree in which different matters possess the property. That magnetic force acts upon the ray of light always with the same character of manner and in the same direction, independent of the different varieties of substance, or their states of solid or liquid, or their specific rotative force (2232), shows that the magnetic force and light have a direct relation; but that substances are necessary, and that these act in different degrees, shows that the magnetism and the light act on each other through the intervention of the matter.

2225. Recognizing or perceiving *matter* only by its powers, and knowing nothing of any imaginary nucleus, abstract from the idea of these powers, the phenomena described in this paper must strengthen my inclination to trust in the views I have on a former occasion advanced in reference to its nature.*

2226. It cannot be doubted that the magnetio forces act upon and affect the internal constitution of the diamagnetic just as freely in the dark as when a ray of light is passing through it; though the phenomena produced by light seem, as yet, to present the only means of observing this constitution and the change. Further, any such change as this must belong to opaque bodies, such as wood, stone, and metal; for as diamagnetics there is no distinction between them and those which are transparent. The degree of transparency can at the utmost, in this respect, only make a distinction between the individuals of a class.

2227. If the magnetic forces had made these bodies magnets, we could, by light, have examined a transparent magnet, and that would have been a great help to our investigation of the forces of matter. But it does not make them magnets (2171), and therefore the molecular condition of these bodies, when in the state described, must be specifically distinct from that of magnetized iron or other such matter, and must be *a new mag-*

---

* "A Speculation," etc., *Phil. Mag.*, xxiv., p. 136, 1844. [*In this paper Faraday advocated Boscovich's hypothesis that atoms are merely centres of force.*]

netic condition; and as the condition is a state of tension (manifested by its instantaneous return to the normal state when the magnetic induction is removed), so the *force* which the matter in this state possesses, and its mode of action, must be to us a new *magnetic force* or *mode of action* of matter.

2228. For it is impossible, I think, to observe and see the action of magnetic forces, rising in intensity, upon a piece of heavy glass or a tube of water, without also perceiving that the latter acquire properties which are not only new to the substance, but are also in subjection to very definite and precise laws (2160, 2199), and are equivalent in proportion to the magnetic forces producing them.

2229. Perhaps this state is a state of *electric tension tending to a current;* as in magnets, according to Ampère's theory, the state is a state of *current.* When a core of iron is put into a helix, everything leads us to believe that currents of electricity are produced within it, which rotate or move in a plane perpendicular to the axis of the helix. If a diamagnetic be placed in the same position, it acquires power to make light rotate in the same plane. The state it has received is a state of tension, but it has not passed on into currents, though the acting force and every other circumstance and condition are the same as those which do produce currents in iron, nickel, cobalt, and such other matters as are fitted to receive them. Hence the idea that there exists in diamagnetics, under such circumstances, a tendency to currents is consistent with all the phenomena as yet described, and is further strengthened by the fact that, leaving the loadstone or the electric current, which by inductive action is rendering a piece of iron, nickel, or cobalt magnetic, perfectly unchanged, a mere change of temperature will take from these bodies their extra power and make them pass into the common class of diamagnetics.

2230. The present is, I believe, the first time that the molecular condition of a body required to produce the circular polarization of light has been artificially given; and it is therefore very interesting to consider this known state and condition of the body, comparing it with the relatively unknown state of those which possess the power naturally; especially as some of the latter rotate to the right hand and others to the left; and as, in the cases of quartz and oil of turpentine, the same body, chemically speaking, being in the latter instance a liquid with particles free to move, presents different specimens, some rotating one way and some the other.

2231. At first one would be inclined to conclude that the natural state and the state conferred by magnetic and electric forces must be the same, since the effect is the same; but on further consideration it seems very difficult to come to such a conclusion. Oil of turpentine will rotate a ray of light, the power depending upon its particles and not upon the arrangement of the mass. Whichever way a ray of polarized light passes through this fluid, it is rotated in the same manner; and rays passing in every possible direction through it *simultaneously* are all rotated with equal force and according to one common law of direction; *i. e.*, either all right-handed or else all to the left. Not so with the rotation superinduced on the *same* oil of turpentine by the magnetic or electric forces: it exists only in one direction, *i. e.*, in a plane perpendicular to the magnetic line; and being limited to this plane, it can be changed in direction by a reversal of the direction of the inducing force. The direction of the rotation produced by the natural state is connected invariably with the direction of the ray of light; but the power to produce it appears to be possessed in every direction and at all times by the particles of the fluid. The direction of the rotation produced by the induced condition is connected invariably with the direction of the magnetic line or the electric current, and the condition is possessed by the particles of matter, but strictly limited by the line or the current, changing and disappearing with it.

[2232, 2233 *omitted.*]

2234. All these differences, however, will doubtless disappear or come into harmony as these investigations are extended; and their very existence opens so many paths by which we may pursue our inquiries, more and more deeply, into the powers and constitution of matter.

2235. Bodies having rotating power of themselves do not seem by that to have a greater or a less tendency to assume a further degree of the same force under the influence of magnetic or electric power.

2236. Were it not for these and other differences we might see an analogy between these bodies, which possess at all times the rotating power, as a specimen of quartz which rotates only in one plane, and those to which the power is given by the induction of other forces, as a prism of heavy glass in a helix on the one hand; and, on the other, a natural magnet and a helix through which the current is passing. The natural condition of the magnet and quartz, and the constrained condition of the helix and heavy glass, form the link of the analogy in one direction; whilst the supposition of currents existing in the magnet and helix, and only a tendency or tension to currents existing in the quartz and heavy glass, supplies the link in the transverse direction.

2237. As to those bodies which seem as yet to give no indication of the power over light, and, therefore, none of the assumption of the new magnetic conditions, these may be divided into two classes, the one including air, gases, and vapors, and the other rock crystal, Iceland spar, and certain other crystalline bodies. As regards the latter class, I shall give, in the next series of these researches, proofs drawn from phenomena of an entirely different kind that they do acquire the new magnetic condition;* and these being so disposed of for the moment, I am inclined to believe that even air and gases have the power to assume the peculiar state, and even to affect light, but in a degree so small that, as yet, it has not been made sensible. Still, the gaseous state is such a remarkable condition of matter that we ought not too hastily to assume that the substances which, in the solid and liquid state, possess properties even general in character, always carry these into their gaseous condition.

2238. Rock-salt, fluor-spar, and, I think, alum, affect the ray of light; the other crystals experimented with did not; these are equiaxed and singly refracting, the others are unequiaxed and doubly refracting. Perhaps these instances, with that of the rotation of quartz, may even now indicate a relation between magnetism, electricity, and the crystallizing forces of matter.

2239. All bodies are affected by helices as by magnets, and according to laws which show that the causes of the action are identical as well as the effects. This result supplies another fine proof in favor of the identity of helices and magnets, according to the views of Ampère.

---

* [*So far as concerns mechanical forces in a magnetic field.*]

2240. The theory of static induction which I formerly ventured to set forth (1161, etc.), and which depends upon the action of the contiguous particles of the dielectric intervening between the electric and the inducteous bodies, led me to expect that the same kind of dependence upon the intervening particles would be found to exist in magnetic action; and I published certain experiments and considerations on this point seven years ago (1709–1736). I could not then discover any peculiar condition of the intervening substance or diamagnetic; but now that I have been able to make out such a state, which is not only a state of tension (2227), but dependent entirely upon the magnetic lines which pass through the substance, I am more than ever encouraged to believe that the view then advanced is correct.

2241. Although the magnetic and electric forces *appear* to exert no power on the ordinary or on the depolarized ray of light, we can hardly doubt but that they have some special influence, which probably will soon be made apparent by experiment; neither can it be supposed otherwise than that the same kind of action should take place on the other forms of radiant agents as heat and chemical force.

2242. This mode of magnetic and chemical action, and the phenomena presented by it, will, I hope, greatly assist hereafter in the investigation of the nature of transparent bodies, of light, of magnets, and their action one on another, or on magnetic substances. I am at this time engaged in investigating the new magnetic condition, and shall shortly send a further account of it to the Royal Society. What the possible effect of the force may be in the earth as a whole, or in magnets, or in relation to the sun, and what may be the best means of causing light to evolve electricity and magnetism, are thoughts continually pressing upon the mind; but it will be better to occupy both time and thought, aided by experiment, in the investigation and development of real truth than to use them in the invention of suppositions which may or may not be founded on or consistent with fact.

ROYAL INSTITUTION, *Oct.* 29, 1845.

ON THE MAGNETIC AFFECTION OF LIGHT

BY

MICHAEL FARADAY, F. R. S.

WHEN a ray of polarized light and lines of magnetic force pass simultaneously and parallel to each other through a transparent solid or liquid medium not possessing forces of double refraction, the ray is rotated according to a simple law of action, which I have expressed in the last part of the *Philosophical Transactions*. [*Omitted.*]

Upon consideration it appeared that the peculiar character of the magnetic rotation might be made available in exalting the final effect of the magnetic force upon the ray, and also in demonstrating many important points in a more marked manner and higher degree than had yet been possible; and upon referring the idea to experiment, it was found to be true. The following pages contain some of the results.

A parallelopiped of heavy glass, 0.7 of an inch square and 2.5 inches long, had the two ends polished and silvered. The silvering was then removed from a space about 0.1 of an inch wide along one of the edges of one end, and also from a corresponding space on the other end, except that the parts cleared were on the contrary sides of the parallelopiped; so that each end was furnished with a good plane reflector, but these overlapped each other (Fig. 1). In consequence of this arrangement, a ray of light could be transmitted diagonally across the length of the piece of glass; or the ray, after entering at one end, could be reflected two or more times within the glass and then passed out.

A similar piece of heavy glass was silvered at the two ends and one side of the prism ; and the silvering was then removed at the ends for the space of 0.1 of an inch from those edges which were the farthest from the silvered side (Fig. 2). A ray of light passing in at the unsilvered part of one end with a certain degree of obliquity could be reflected at the other end, then at the side, and again at the first end, passing thus three times along the glass and finally out at the second end. At other inclinations the ray would pass five, seven, nine, eleven, or a greater number of times along the glass before it issued forth on its course through the air to the eye of the observer.

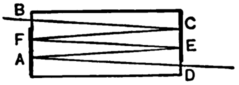

Fig. 1

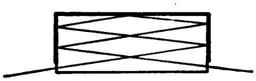

Fig. 2

Either of these pieces of glass could produce the desired result of repeated reflections within, but the first form was found most convenient in use. When a strong light was employed, it was not difficult to follow the series of images produced by successive reflection up to the ninth or tenth image, these corresponding, of course, to a transit of the ray seventeen or nineteen times along the substance of the glass. A little change of position of the silvered glass between the Nicol's prisms used as the polarizing and analyzing apparatus was sufficient to bring any one of these images into view, the glass being at the same time under the full influence of the electromagnet or the helix employed to generate lines of magnetic force. A further advantage is gained if the ends of the piece of glass are not quite parallel to each other, the sides proceeding from the edges where the ray enters and issues forth being in a very slight degree different in length. This arrangement causes the series of reflected images to open out if seen at one end and to close up if seen at the other, and thus the observation of a particular image or the simultaneous comparison of two or more images is favored.

On considering the effect of this arrangement, it is evident that if ABCD represent a trough of solution of sugar, or any other body having the ordinary rotating influence over a polarized ray, then a ray sent in at D and passing out at A would be rotated to a certain amount. But if, instead of proceeding onward at A, it were reflected by the surface AF to E, and were there observed, it would be found to have received no rotation, for the effect produced in going from D to A would be exactly compensated by its return from A to E. Or, if the reflections were made more numerous and recurred at E, F, and C, so that the ray should traverse the body five times, still an amount of rotation equal only to that which its passage once along the substance could effect would be finally produced.

Such would not be the case if ABCD were a diamagnetic, rotating the ray by means of magnetic force; for then, whichever way the ray was passing, it would still be rotated in the *same* direction in relation to the lines of force. So if observed issuing forth at A, it would have an amount of rotation (which we may call right-handed) equal to what one transit across the diamagnetic could produce; if observed at E, it would have an amount of left-handed rotation double the amount of the first or unit quantity; if observed at F, it would have three times the first amount of right-handed rotation; if observed at C, four times the amount of left-handed rotation; and at B would possess five times the original amount of right-handed rotation.

This was confirmed by the result of an experiment. [*Omitted.*]

Having ascertained the great advantage which this form of apparatus possessed for the examination of many substances which would give no sensible results by the process I formerly described, I proceeded to apply it to the cases of air and some doubly refracting bodies (*Experimental Researches*, 2237). For this purpose I made the faces of the magnetic poles reflectors, by applying to each a polished plate of steel; and as the poles were movable, their reflecting surfaces could be placed at any distance and in any position required, the substance experimented on being between them.

Air.—I could obtain no signs of action upon the ray when air was between the magnetic poles, even with the fourth, fifth, and sixth images.

Rock crystal.—The cubes of this substance, formerly described (*Experimental Researches*, 2178), were submitted to examination; but I could detect no trace of action on the ray of light when passing through them, although they were 0.75 of an inch on the side, and the ray was observed after passing seven and even nine times across them. The cubes were examined in all directions.

Iceland spar.—A cube of this substance (*Experimental Researches,* 2179) was examined in the same manner, but I obtained no effect.

Heavy glass presented the expected phenomena easily and well.

Failing to procure any positive result in these trials, either with air or with doubly refracting crystals, I silvered the latter in the manner that had been employed for the heavy glass, that the magnetic poles might be brought as close as possible; still no evidence of any magnetic action on the ray could be observed.

A natural six-sided prism of rock crystal, 2.3 inches in length, was polished and silvered at the ends; no magnetic effect upon the light could be observed with this crystal with either the first, second, or third image.

M. E. Becquerel thinks that he has observed an effect produced in doubly refracting crystalline bodies, and it is probable that his apparatus is far more delicate for the observance of optical changes than mine. In that case, if combined with the procedure founded on repeated transits of the ray, it perhaps would produce very distinct results; but the latter process alone has not as yet given any evidence of the action sought after.

Certain indications led me to look with interest for any possible effect which the crossing of the reflected rays might produce in the arrangement of the reflectors and glass represented in Fig. 2; but I could find no difference of action between it and the other arrangement, Fig. 1, in which no such crossing occurred.

ROYAL INSTITUTION, *August* 11, 1846.

MICHAEL FARADAY was born September 22, 1791, at Newington, near London, and died August 25, 1867, at Hampton Court. He wrote of himself: "My education was of the most ordinary description, consisting of little more than the rudiments of reading, writing, and arithmetic, at a common day school." In 1804 he became an errand boy, and in 1805 an apprentice in a stationer and bookbinder's shop. Some of the books that passed through his hands aroused an interest in scientific subjects, and he repeated many of the simpler experiments described in them. In 1810 and 1811 he attended a course of lectures on natural philosophy, and in 1812 heard some lectures on chemistry by Sir Humphry Davy. The latter appointed him an assistant in the Royal Institution in 1813. In 1824 he became a member of the Royal Society, and in 1825 a member of the Royal Institution and director of its laboratory. With the exception of a few years of ill-health, his life until 1862 was one of continuous activity and discovery. For some years longer he carried on administrative and advisory work, but in 1865 he withdrew entirely from active life.

His earlier work was on chemical subjects. In 1831 he began his long series of Electrical Researches. His most important contributions to science were:

1. The discovery of electromagnetic rotation (1821).
2. The liquefaction of gases (1823 and 1844).
3. The discovery of electromagnetic induction (1831).
4. The investigation of the phenomena of electrolysis (1833).
5. The discovery of self-induced electric currents (1834).
6. The discovery of rotation of the plane of polarization of light by substances in a magnetic field (1845).
7. The investigation of diamagnetic phenomena (1845).

His last experiment, made in 1862, was an attempt to discover an effect of magnetism on spectra—the effect which was found by Zeeman in 1897.

The value of his work was widely recognized. He was a member of the most important scientific societies of Europe and America, and received ninety-five honorary titles and orders of merit.

Not only did he contribute more than any other one man to our experimental knowledge of electric and magnetic phenomena, but his speculations as to the important part played by the ether in these phenomena have been fully substantiated by all later investigations.